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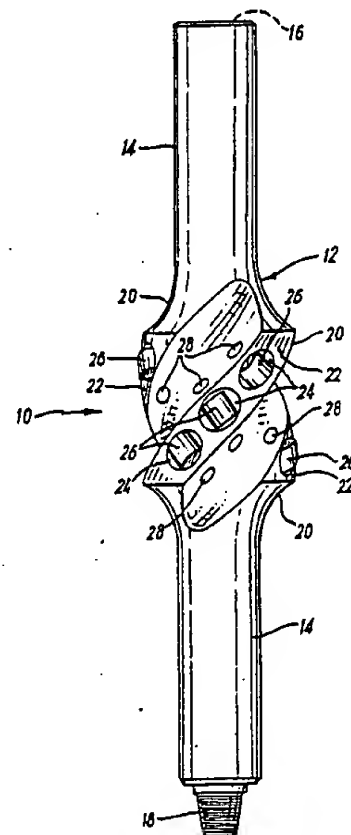
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(54) Title: DOWNHOLE TOOLS

## (57) Abstract

A downhole tool for providing rotary support of a downhole assembly in which the tool is incorporated, the tool also converting rotary contact with the wellbore to a longitudinal force tending to propel the assembly along the wellbore. The tool resembles a roller stabiliser in which the roller axes are skewed to be tangential to a notional helix, such that the natural (non-slipping) paths of roller contact with the wellbore have a longitudinal component in addition to the usual circumferential path. The tool can be used on drillstrings and in downhole motor assemblies. The invention has particular advantage in highly deviated wells since it simultaneously compensates for increased bore friction and dynamically enhances weight-on-bit.



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1     Downhole Tools

2

3     This invention relates to downhole tools, and relates  
4     more particularly but not exclusively to downhole tools  
5     in the form of well-drilling tools which facilitate the  
6     drilling of wells which are substantially non-vertical.

7

8     BACKGROUND:

9

10    As oil and gas reserves become scarcer or depleted,  
11    methods for more efficient production have to be  
12    developed.

13

14    In recent years horizontal drilling has proved to  
15    enhance greatly the rate of production from wells  
16    producing in tight or depleted formation. Tight  
17    formations typically are hydrocarbon-bearing formations  
18    with poor permeability, such as the Austin Chalk in the  
19    United States and the Danian Chalk in the Danish Sector  
20    of the North Sea.

21

22    In these tight formations oil production rates have  
23    dropped rapidly when conventional wells have been  
24    drilled. This is due to the small section of producing

1 formation open to the well bore.

2

3 However when the well bore has been drilled  
4 horizontally through the oil producing zones, the  
5 producing section of the hole is greatly extended  
6 resulting in dramatic increases in production. This  
7 has also proved to be effective in depleted formations  
8 which have been produced for some years and have  
9 dropped in production output.

10

11 However, horizontal drilling has many inherent  
12 difficulties. In broad terms the difficulties include  
13 the following factors:

14

15 (i) the rotational torque requirement of the  
16 drillstring rises rapidly with increasing hole  
17 angle (angular displacement from vertical) and  
18 length of the horizontal section,

19

20 (ii) the weight of the drillstring in the vertical  
21 section of the hole must push the drillpipe along  
22 the horizontal section thereby increasing the  
23 fatigue stresses in the drillpipe located on the  
24 bend between the two sections,

25

26 and

27

28 (iii) performance of the drillbit is reduced due to  
29 both (i) and (ii) above as difficulties in  
30 applying weight and torque affect the ROP ("rate  
31 of progress" in deepening/lengthening of the  
32 well).

33

## 1 PRIOR ART:

2  
3 Conventional stabilisers used in assemblies for  
4 horizontal drilling do little to resolve the above  
5 problems. Conventional stabilisers have fixed blades  
6 which normally are spiralled to distribute well contact  
7 area whilst still allowing fluid bypass. Conventional  
8 stabilisers also generate quite considerable back  
9 torque and resistance to forward motion although they  
10 do centralise the drilling assembly and play an  
11 important role in directional control of the hole.

12  
13 A number of attempts have been made to reduce friction  
14 by the development of rolling element stabilisers. A  
15 recent one of these stabiliser tools (described in  
16 published European Patent Application EP0333450-A1)  
17 used freely rotating balls set into the stabiliser  
18 blades which addressed points (i) and (ii) above.  
19 Initially the tool was well received by the oil  
20 industry as there was a real need to resolve the  
21 downhole torque problems. Unfortunately the tool  
22 proved to have problems with the balls packing off and  
23 locking with cutting debris. This considerably reduced  
24 the market interest in this tool.

25  
26 Another known form of rolling element stabiliser is  
27 based on rollers mounted on respective axes which are  
28 each parallel to the longitudinal axis of the  
29 stabiliser and hence parallel to the longitudinal axis  
30 of the drillstring and of the well drilled thereby.  
31 Examples of this form of roller stabiliser are  
32 described in United States Patent US3907048 and United  
33 Kingdom Patent Specification GB271839. The functional  
34 effect of this form of roller stabiliser is to reduce  
35 rotational friction (by reason of the rolling support

1 of the stabiliser against the bore of the well or well  
2 casing), but to have a neutral longitudinal effect (by  
3 reason of the parallelism of the roller axes with  
4 respect to the longitudinal axis of the stabiliser and  
5 the drillstring incorporating the stabiliser).

6  
7 A still further form of rolling element stabiliser  
8 which purports to reduce both rotational and  
9 longitudinal friction is described in United States  
10 Patent US1913365. This further form of roller  
11 stabiliser essentially comprises a collar which is  
12 rotatably mounted on the exterior of a drillstring by  
13 two rows of vertical-axis rollers, ie rollers whose  
14 respective axes are each parallel to and radially  
15 offset from the longitudinal axis of the drillstring.  
16 (These vertical-axis rollers are externally spherically  
17 shaped, and therefore superficially appear as balls,  
18 although they are actually rollers). While the collar  
19 is free to rotate on the drillstring (by reason of the  
20 rolling support provided by the vertical-axis rollers),  
21 the collar is longitudinally retained at a fixed  
22 position on the drillstring by end rings clamped to the  
23 drillstring. The collar provides longitudinal rolling  
24 support for the drillstring by means of an external  
25 array of horizontal-axis rollers, ie rollers whose  
26 respective axes are each tangential to a circle centred  
27 on the longitudinal axis of the drillstring. Thus  
28 although this further form of roller stabiliser  
29 provides both rotational and longitudinal rolling  
30 support for the drillstring, it is to be noted that the  
31 purely longitudinal ("vertical") and circumferential  
32 ("horizontal") roller axes result in the facts that  
33 rotational movement of the drillstring does not result  
34 in a net longitudinal force, nor does longitudinal  
35 movement of the drillstring result in a net rotational

1 force, ie there is no cross-translation of motion and  
2 force between rotational and longitudinal directions.

3  
4 United States Patent US4000783 describes a roller  
5 reamer, ie a form of annular drilling bit for  
6 substantially enlarging the bore of a pilot hole. In  
7 this roller reamer, the conical reamers or cutters are  
8 rotatably mounted on respective axes that are each  
9 triply offset from the longitudinal axis of the  
10 drillstring, being offset radially outwards, obliquely  
11 (ie conically), and skewed (ie helical) with respect to  
12 the drillstring axis. The conical reamers enlarge a  
13 previously-drilled hole by gouging away the wall of the  
14 pilot hole in an annular region around the tool. It is  
15 said that if the reamers are disposed at a skew angle  
16 which is greater than the neutral skew angle, the  
17 cutters provide a self-advancing action. It is to be  
18 noted that the conical reamers or cutters of US4000783  
19 provide a purely cutting action, with radial support of  
20 this cutting tool being provided by purely static  
21 cylindrical shoulders ahead of and behind the cutters  
22 (see Fig. 1 of US4000783), a smaller diameter shoulder  
23 providing radial support in the pilot hole, and a  
24 larger diameter shoulder providing radial support in  
25 the enlarged bore. These radial support shoulders are  
26 concentric with the longitudinal axis of the tool and  
27 of the drillstring.

28  
29 OBJECTS OF THE INVENTION:

30  
31 It is an object of the invention to provide a downhole  
32 tool which provides radial support for a rotatable  
33 downhole assembly in a previously drilled hole of  
34 substantially uniform diameter, the radial support  
35 being provided by a rolling element arrangement which

1 translates rotational movement of the tool to a  
2 longitudinal force on the tool.

3

4

5 SUMMARY OF THE INVENTION:

6

7 According to a first aspect of the present invention  
8 there is provided a downhole tool for providing radial  
9 support for a rotatable downhole assembly within a  
10 previously drilled hole of substantially uniform  
11 diameter, said tool comprising a central member  
12 constructed or adapted to be incorporated in a  
13 rotatable downhole assembly for rotation therewith in  
14 use of said tool, said central member mounting a  
15 plurality of rolling element means in respective  
16 positions which are circumferentially distributed  
17 around said tool, each said rolling element means being  
18 rotatably mounted on a respective axis which is  
19 tangential to a notional helix substantially coaxial  
20 with the longitudinal axis of said tool about which  
21 said tool rotates in use of said tool such that each  
22 said respective axis of said rolling element means is  
23 skewed with respect to said longitudinal axis, each  
24 said rolling element means having a respective  
25 periphery which extends to the radially outermost  
26 periphery of said tool whereby the radially outermost  
27 periphery of said tool provides rolling radial support  
28 for said rotatable downhole assembly in use of said  
29 tool by means of the peripheries of said rolling  
30 element means and the rotation of said rolling element  
31 means about their skewed axes translates rotation of  
32 said tool in use thereof to a longitudinally-directed  
33 force acting through said central member on said  
34 downhole assembly.

35

1 Said rotatable downhole assembly may be a drillstring  
2 and said notional helix is preferably contra-rotary  
3 with respect to the combination of the normal or  
4 forward direction of rotation of the drillstring and  
5 the direction from said tool towards a drill bit at the  
6 downhole end of the drillstring, whereby normal or  
7 forward rotation of said drillstring and of the tool  
8 incorporated therein results in a longitudinal force  
9 tending to propel the drillstring towards the blind end  
10 of the bore and ultimately tending to force the drill  
11 bit into the geological material to be drilled. Thus  
12 if the normal or forward direction of rotation of the  
13 drillstring is clockwise as viewed from the surface and  
14 looking down into the bore, said notional helix  
15 preferably progresses anti-clockwise in a downhole  
16 direction therealong whereby the peripheries of said  
17 rolling element means, where they extend to the  
18 radially outermost periphery of the tool, align with a  
19 notional right-hand thread around the outer periphery  
20 of said tool.

21  
22 Each respective axis of said rolling element means is  
23 preferably skewed with respect to the longitudinal axis  
24 of the tool at an angle in the range from a very low  
25 (but non-zero) angle, up to 45°, and more preferably at  
26 an angle in the range from 0.5° to 15°. Said downhole  
27 tool may incorporate skew angle variation means  
28 operable to make the skew angle controllably variable,  
29 and possibly capable of reversing the hand of said  
30 notional helix whereby the direction of longitudinal  
31 force is reversed without reversing the direction of  
32 rotation.

33  
34 Said rolling element means are preferably rollers, and  
35 the peripheries of said rollers may individually be

1 cylindrical or crowned (ie having relatively larger  
2 diameter mid-length portion reducing continuously or  
3 discontinuously to a relatively smaller diameter at  
4 either end). Said rollers may be individually mounted  
5 on a respective axis, or said rollers may be mounted in  
6 coaxial groups, preferably such that within a group of  
7 rollers, individual rollers of that group are capable  
8 of rotating at mutually differing rotational rates.

9  
10 Radial force applying means are preferably incorporated  
11 in the tool for applying radially outwardly directed  
12 radial forces to the rolling element means to increase  
13 their traction on the bore. The radial force applying  
14 means may be such that the radially outwardly directed  
15 radial forces applied to the rolling element means are  
16 controllably variable.

17  
18 The central member of the tool may be adapted from a  
19 conventional fixed-blade stabiliser by reducing the  
20 outside diameter slightly below the nominal diameter of  
21 the bore of the well in which the tool is to be used,  
22 machining or otherwise forming pockets or recesses in  
23 the blades, and mounting a roller assembly in each of  
24 these pockets or recesses such that the rollers project  
25 to define the gauge or radially outermost periphery of  
26 the tool at the nominal well bore diameter. Each  
27 roller assembly can comprise a single roller or a group  
28 of rollers mounted on an axle which is rotatably  
29 mounted at each end thereof by a suitable combination  
30 of radial bearings and thrust bearings.

31  
32 According to a second aspect of the present invention  
33 there is provided a rotatable downhole assembly for  
34 rotatable operation within a previously drilled hole of  
35 substantially uniform diameter, said downhole assembly

1 comprising a downhole motor having a motor housing and  
2 a rotatable motor output shaft coupled to a rotatable  
3 motor output utilisation means, said downhole assembly  
4 further comprising at least one downhole tool according  
5 to the first aspect of the present invention, said at  
6 least one downhole tool being coupled between said  
7 rotatable motor output shaft and said rotatable motor  
8 output utilisation means for rotation therewith in  
9 operation of said assembly to provide radial support  
10 therefor and to translate such rotation to a  
11 longitudinally-directed force acting through said motor  
12 output utilisation means.

13  
14 Said downhole assembly may comprise a plurality of such  
15 downhole tools, each according to the first aspect of  
16 the present invention, and each being coupled between  
17 said rotatable motor output shaft and said rotatable  
18 motor output utilisation means, said tools being  
19 optionally mutually separated by one or more drill  
20 collars or other suitable longitudinal spacer means  
21 serving in operation of said assembly to convey torque,  
22 rotation, and longitudinal forces between parts of said  
23 assembly mutually separated by such spacer means.

24  
25 Said rotatable motor output utilisation means may  
26 comprise a drill bit, said at least one downhole tool  
27 comprised in said downhole assembly being formed  
28 dynamically to increase the effective weight-on-bit  
29 during normally directed rotation of said drill bit by  
30 said downhole motor.

31  
32 Said motor housing is preferably coupled to  
33 countertorque means for reacting motor torque output by  
34 said motor output shaft, said countertorque means  
35 rotationally constraining said motor housing with

1 respect to said previously drilled hole. Said  
2 countertorque means may provide a rotational braking  
3 effect while allowing relative freedom of movement in a  
4 longitudinal direction, preferably by forming said  
5 countertorque means with a peripheral array of  
6 hole-contacting rotatable rollers having their axes of  
7 rotation substantially tangential to notional circles  
8 substantially coaxial with the longitudinal axis of  
9 said downhole assembly. Alternatively, said  
10 countertorque means may comprise a further downhole  
11 tool in accordance with the first aspect of the present  
12 invention, the notional helix of said further downhole  
13 tool being oppositely handed with respect to the  
14 notional helix of said at least one downhole tool  
15 coupled between said rotatable motor output shaft and  
16 said rotatable motor output utilisation means whereby  
17 relative contrarotation of said motor housing with  
18 respect to said motor output shaft results in commonly  
19 directed longitudinal forces at said at least one and  
20 further downhole tools comprised in said downhole  
21 assembly.

22  
23 The motor of said downhole assembly may be a hydraulic  
24 motor supplied in operation thereof with pressurised  
25 fluid by way of tubing which may be flexible (ie,  
26 tubing which is known in the art as "coiled tubing"),  
27 said downhole assembly preferably being coupled to said  
28 tubing by way of a swivel coupling which is preferably  
29 substantially fluid-tight.

30  
31 Said downhole assembly may have major components and  
32 sub-assemblies thereof longitudinally coupled by one or  
33 more couplings transmissive of torque and longitudinal  
34 forces but yieldable about axes transverse to the  
35 longitudinal axis whereby the downhole assembly may

1 conform to bent holes.

2

3 DESCRIPTION OF EXEMPLARY EMBODIMENTS:

4

5 Embodiments of the present invention will now be  
6 described by way of example, with reference to the  
7 accompanying drawings wherein:-

8

9 Fig. 1 is an elevational view of a first  
10 embodiment of the present invention;

11 Fig. 2 is an elevational view of a form of roller  
12 suitable for use with the present invention;

13 Fig. 3 is an elevational view of another form of  
14 roller suitable for use with the present

15 invention;

16 Figs. 4 and 5 are respectively an elevational view  
17 and a plan view of a second embodiment of the  
18 present invention;

19 Fig. 6 and 7 are respectively an elevational view  
20 and a plan view of a third embodiment of the  
21 present invention;

22 Fig. 8 is an elevational view of a fourth  
23 embodiment of the present invention;

24 Fig. 9 is a schematic longitudinal elevation of a  
25 fifth embodiment of the present invention;

26 Fig. 10 is a schematic longitudinal elevation of a  
27 sixth embodiment of the present invention;

28 Fig. 11 is a schematic longitudinal elevation of a  
29 seventh embodiment of the present invention;

30 Figs 12 and 13 are respectively an elevational  
31 view and a plan view of an eighth embodiment of  
32 the present invention;

33 Fig. 14 is a schematic longitudinal elevation of a  
34 ninth embodiment of the present invention;

35 Figs 15 and 16 are elevational views of a tenth

1 embodiment of the present invention, taken in  
2 mutually orthogonal directions;  
3 Fig. 17 is a perspective view of an eleventh  
4 embodiment of the present invention;  
5 Figs 18 and 19 are respectively schematic  
6 elevational and plan views of a twelfth embodiment  
7 of the present invention; and  
8 Figs 20 and 21 are respectively schematic  
9 elevational and plan views of a thirteenth  
10 embodiment of the present invention.

11  
12 Referring first to Fig. 1, a first embodiment of  
13 downhole tool 10 in accordance with the present  
14 invention comprises a central member 12 whose form is  
15 generally that of a conventional fixed-blade  
16 stabiliser. The central member 12 comprises a hollow  
17 shaft 14 having a standard A.P.I. (American Petroleum  
18 Institute) box connector 16 at the upper end and a  
19 standard A.P.I. pin connector 18 at the lower end for  
20 connection of the tool 10 in a conventional drillstring  
21 (not shown).

22  
23 The shaft 14 of the central member 12 has three spiral  
24 blades 20 formed integrally thereon, each of the blades  
25 20 describing a clockwise helix. The radially outer  
26 edge 22 of each blade 20 has a radius (measured from  
27 the longitudinal axis of the tool 10) which is slightly  
28 less than the nominal gauge of the tool 10, ie a radius  
29 slightly less than the radius of the bore in which the  
30 tool 10 is designed to be used.

31  
32 Three pockets 24 are cut through each outer edge 22 and  
33 into the bodies of the blades 20. Within each pocket  
34 24, a roller 26 is rotatably mounted on a respective  
35 axle 28 such that part of the outer periphery of each

1 roller 26 radially extends beyond the respective outer  
2 edge 22 of the respective blade 20 to define the  
3 radially outermost periphery of the tool 10.

4  
5 Each of the roller axles 28 is skewed with respect to  
6 the longitudinal axis of the tool 10 about which the  
7 tool 10 rotates in use thereof, ie each roller axle 28  
8 is tangential to a respective notional helix  
9 substantially coaxial with the longitudinal axis of the  
10 tool 10 and spiralling anti-clockwise in a downward  
11 direction (ie each notional helix is of opposite hand  
12 to the illustrated helical shape of the blades 20). As  
13 shown in Fig. 1, the roller axles 28 extend  
14 transversely of the blades 20, and therefore a notional  
15 point on the outer periphery of any one of the rollers  
16 26 would, as the roller rotated and where the notional  
17 point was proud of the respective blade 20, describe a  
18 path generally along the line of the outer edge 22 of  
19 that blade, ie a notional right-hand thread around the  
20 outer periphery of the tool 10.

21  
22 The result of this roller mounting configuration is  
23 that the array of rollers 26 provides rolling support  
24 for the tool 10, and hence for the drillstring in which  
25 it is incorporated, by bearing against the  
26 substantially uniform diameter bore of the hole drilled  
27 by the drilling bit above which the tool 20 is fitted,  
28 while simultaneously reacting with the bore to  
29 translate the clockwise rotation of the tool 10 (as  
30 viewed from above and looking downhole) into a  
31 downwardly-directed longitudinal force by reason of the  
32 skewing of each roller 26 as described above. Thus, in  
33 normal drilling operations while the drillstring is  
34 rotating clockwise (as viewed from above and looking  
35 downhole), the tool 10 will cause the drillstring to

1 "walk" downhole, so enhancing the pressure on the drill  
2 bit and improving ROP. This beneficial and desirable  
3 effect is enhanced by increased side-loading on the  
4 tool 10, such as will be experienced as the bore  
5 increasingly deviates from vertical, to reach a maximum  
6 in horizontal stretches of the bore (where the weight  
7 of the horizontal sections of the drillstring is  
8 ineffective to push the drill bit forwards). It is  
9 also in such deviated and ultimately horizontal  
10 stretches of the bore that low-friction radial support  
11 of the drillstring is most required, and is provided by  
12 the tool 10 simultaneously with the above-described  
13 tractive effort.

14  
15 The skew angle at which each of the rollers 26 is  
16 mounted on the tool 10 may be any non-zero angle from a  
17 very small angle (eg, under 1°) up to about 45° (or  
18 greater in appropriate circumstances), and is  
19 preferably in the range 0.5°- 15°. The skew angle is  
20 preferably selected to give a greater rate of  
21 theoretical progress (as denoted by the pitch of the  
22 above-mentioned notional thread) than the maximum ROP  
23 practically achievable by the drill bit, such that  
24 there is always a forward (downhole-directed) tractive  
25 effort during forward (clockwise) rotation of the  
26 drillstring.

27  
28 As is clearly shown in Fig. 1, the rollers 26 are  
29 angularly distributed around the periphery of the tool  
30 10, thus tending to give a relatively uniform loading  
31 on the bore of the well in which the tool 10 is being  
32 used. It should be noted that the well bore will  
33 necessarily be of a substantially uniform diameter in  
34 those parts of the bore in which the tool 10 is used,  
35 since the tool 10 is devoid of any cutting, chiselling,

1 reaming, or gouging action. Indeed, any such reaming  
2 action is undesirable, and is avoided at least partly  
3 by the suitable distribution of the rollers 26 and by  
4 the form of their peripheries (of which more details  
5 are given below).

6  
7 Reversal of the direction of rotation of the  
8 drillstring (ie rotation of the drillstring in an  
9 anti-clockwise direction as viewed from above and  
10 looking downhole) will result in concomitant reversal  
11 of the above-described longitudinal force to give an  
12 uphole-directed tractive effort which will assist in  
13 withdrawal of the drillstring from the well.  
14 Nevertheless, the desirable low-friction radial support  
15 of the drillstring provided by the tool 10 incorporated  
16 therein will be maintained even during such reverse  
17 rotation.

18  
19 Referring now to Figs. 2 and 3, these show two forms of  
20 roller suitable for use in the present invention.  
21 In Fig. 2, the roller 200 is a crown roller having a  
22 (schematically depicted) rotation axis 202. The  
23 diameter of the roller periphery 204 varies smoothly  
24 (continuously) from a maximum at the mid-length to a  
25 somewhat lesser diameter at each end. The length of  
26 the roller 200 (as measured along its rotation axis  
27 202) is similar to the maximum diameter of its  
28 periphery 204. Crowning of the roller periphery 204  
29 enhances distribution of the loading on the roller 200  
30 in its contact with the bore of the well, as does  
31 avoidance of discontinuous changes in peripheral  
32 diameter.

33  
34 In Fig. 3, the roller 300 is a barrel roller having a  
35 schematically depicted rotation axis 302. The roller

1 periphery 304 has a mid-length section 306 of  
2 substantially constant diameter which merges into  
3 conically tapering sections 308 at each end of the  
4 roller 300. The length of the roller 300 (as measured  
5 along its rotation axis 302) is a small multiple of the  
6 maximum diameter of its periphery 304 (ie the diameter  
7 of the mid-length periphery section 306).

8  
9 Referring now to Figs. 4 and 5, these respectively  
10 illustrate an elevation and a plan view of a second  
11 embodiment of downhole tool 410 in accordance with the  
12 present invention. The tool 410 is generally similar  
13 to the tool 10 previously described with reference to  
14 Fig. 1, and accordingly those parts of the tool 410  
15 which are identical or equivalent to parts of the tool  
16 10 will be given the same reference numerals, but  
17 preceded by a "4" (ie the Fig. 1 reference numerals  
18 plus 400). The following description will concentrate  
19 principally on those parts of the tool 410 which differ  
20 from the tool 10, and for a detailed description of  
21 parts of the tool 410 not described below, reference  
22 should be made to the relevant parts of the foregoing  
23 description of the tool 10.

24  
25 Apart from some differences in dimensional proportions  
26 (principally an increase in relative lengths), the  
27 major difference in the tool 410 with respect to the  
28 tool 10 lies in a substantial increase in the numbers  
29 of rollers mounted in the periphery of the tool 410.  
30 As shown in Fig. 4, a correspondingly increased number  
31 of pockets 424 is cut through each outer edge 422 and  
32 into the bodies of the blades 420. The rollers mounted  
33 one in each of the pockets 424 are omitted from Figs. 4  
34 and 5, but are similar to the rollers 26 in the tool 10  
35 as shown in Fig. 1; in particular the skewing of the

1 roller axles in the tool 410 is essentially the same as  
2 in the tool 10. The performance and functions of the  
3 tool 410 are as described above in respect of the tool  
4 10, save for the effects of the increased number of  
5 rollers.

6  
7 Referring now to Figs. 6 and 7, these respectively  
8 illustrate an elevation and a plan view of a third  
9 embodiment of downhole tool 510 in accordance with the  
10 present invention. The tool 510 is similar to the tool  
11 410 described above with reference to Figs. 4 and 5,  
12 and accordingly those parts of the tool 510 which are  
13 identical or equivalent to parts of the tool 410 will  
14 be given the same reference numerals, but with the  
15 leading "4" substituted by a "5". The following  
16 description will concentrate principally on those parts  
17 of the tool 510 which differ from the tool 410, and for  
18 a detailed description of parts of the tool 510 not  
19 described below, reference should be made to the  
20 relevant parts of the foregoing descriptions of the  
21 tools 410 and 10.

22

23 The major difference in the tool 510 with respect to  
24 the tool 410 lies in the replacement of the crown  
25 rollers of the second embodiment with a much increased  
26 number of needle rollers. Accordingly, the  
27 approximately circular roller pockets 424 of the second  
28 embodiment are replaced by a correspondingly greater  
29 number of relatively narrow roller pockets 524 cut  
30 through each outer edge 522 and into the bodies of the  
31 blades 520. The needle rollers mounted one in each of  
32 the pockets 524 are omitted from Figs. 6 and 7, but are  
33 mounted with their rotation axis each transverse the  
34 respective blade 520. Because of the relatively small  
35 diameter and relatively great length/diameter ratio of

1 the needle rollers of the third embodiment, it is  
2 preferred to mount the needle rollers each in a  
3 suitably re-entrant pocket, preferably lined with a  
4 suitable bearing material, to retain the rollers in the  
5 tool 510, rather than to mount the rollers on  
6 individual axles as in the other embodiments of the  
7 present invention. Nevertheless, the rotational  
8 alignment of each of the needle rollers of the third  
9 embodiment is essentially the same as for the rollers  
10 of the other embodiments. The performance and function  
11 of the tool 510 is the same described above in respect  
12 of the tools 10 and 410, save for the effects of the  
13 number, size, and shape of the needle rollers.

14  
15 Turning now to Fig. 8, this illustrates a downhole tool  
16 610 which is a fourth embodiment of the present  
17 invention. The tool 610 comprises a central member 612  
18 which has the form of a fixed-blade stabiliser with a  
19 hollow shaft 614 having a standard A.P.I. box connector  
20 616 at the upper end, and a standard A.P.I. pin  
21 connector 618 at the lower end for connection of the  
22 tool 610 in a conventional drillstring (not shown).

23  
24 The shaft 614 of the central member 612 has three  
25 spiral blades 620 formed integrally thereon, each of  
26 the blades 620 describing an anti-clockwise helix or  
27 left-handed spiral. (This is in contrast to the blades  
28 20 in the tool 10, which each describe a clockwise  
29 helix or right-handed spiral). The radially outer edge  
30 622 of each blade 620 has a radius (measured from the  
31 longitudinal axis of the tool 610) which is slightly  
32 less than the nominal gauge of the tool 610, ie a  
33 radius slightly less than the radius of the bore in  
34 which the tool 610 is designed to be used.

35

1 A recess 624 is cut from the outer edge 622 and into  
2 the body of each blade 620. Within each pocket 624, a  
3 roller assembly 626 is rotatably mounted on a  
4 respective axle 628 such that part of the outer  
5 periphery of each roller assembly 626 radially extends  
6 beyond the respective outer edge 622 of the respective  
7 blade 620 to define the radially outermost periphery of  
8 the tool 610.

9  
10 Each of the roller assembly axles 628 is skewed with  
11 respect to the longitudinal axis of the tool 610 about  
12 which the tool 610 rotates in use thereof, ie each  
13 roller assembly axle 628 is tangential to a respective  
14 notional helix substantially coaxial with the  
15 longitudinal axis of the tool 610 and spiralling  
16 anti-clockwise in a downward direction (ie each  
17 notional helix is of the same hand as the illustrated  
18 helical shape of the blades 620, and in a preferred  
19 form of the fourth embodiment, each notional helix is  
20 substantially coincident with the centre-line of the  
21 respective helical blade 620). As shown in Fig. 8, the  
22 roller assembly axles 628 extend longitudinally of the  
23 blades 620, and therefore a notional point in the outer  
24 periphery of any one of the roller assemblies 626  
25 would, as the roller assembly rotated and where the  
26 notional point was proud of the respective blade 620,  
27 describe a path generally transverse the outer edge 622  
28 of that blade, ie a notional right-hand thread around  
29 the outer periphery of the tool 610.

30  
31 Each of the roller assemblies 626 comprises a group of  
32 rollers 630 coaxially mounted side-by-side along the  
33 respective axle 628 such that each roller 630 can  
34 individually rotate independently of its neighbours,  
35 thereby permitting traction without slippage due to

1 differential rotational velocities along the roller  
2 assembly 626. The overall profile of each roller  
3 assembly 626 is ellipsoidal or hyperboloidal to suit  
4 the circumferential curvature of the well bore in which  
5 the tool 610 is used, in conjunction with the selected  
6 skew angle of the axles 628 (this skew angle preferably  
7 being in the range  $0.5^{\circ}$ -  $15^{\circ}$ , and possibly up to about  
8  $45^{\circ}$ ). End sections 632 of the roller assemblies 626  
9 may be peripherally faced with wear-resisting inserts  
10 634 (eg of tungsten carbide).

11  
12 Opposite ends of each roller assembly axle 628 are  
13 housed in uncutaway portions of the body of the  
14 respective blade 620 wherein radial loading on the  
15 respective axle 628 is sustained by radial bearings,  
16 and axial loading is sustained by suitable axial  
17 bearings. In order to give access to a longitudinal  
18 axle-accommodating bore through the body of each blade  
19 620 from the lower end face thereof, the shaft 614 of  
20 the central member 612 is made in two parts mutually  
21 connected by a standard A.P.I. pin and box connector  
22 636 (shown in ghost outline) joining the two shaft  
23 parts immediately below the lower end faces of the  
24 blades 620.

25  
26 Each roller assembly axle bearing arrangement may be  
27 provided with a pressure-compensated grease reservoir  
28 638 (only one being visible in Fig. 8) to provide  
29 lubrication therefor in a manner which inhibits the  
30 ingress of drilling debris and other foreign material.

31  
32 The portions of the blade edges 622 not cut away to  
33 form the roller assembly recesses 624 may be faced with  
34 wear-resisting inserts 640 (eg of tungsten carbide) to  
35 mitigate the effects of unintended direct contact of

1 the blade edges 622 with the well bore, such as may  
2 occur in the event of excessive wear of the roller  
3 assemblies 626 or collapse of their axles 628 or of  
4 their bearings.

5  
6 Normal operation of the downhole tool 610 is as  
7 described above in respect of the downhole tool 10.

8  
9 Referring now to Fig. 9, this schematically depicts a  
10 longitudinal elevation of a downhole assembly 700 in  
11 accordance with the present invention. The assembly  
12 700 comprises a downhole motor 702 having a motor  
13 housing 704 and a rotatable motor output shaft 706.  
14 The motor shaft 706 is coupled through a first downhole  
15 tool 708, a drill collar 710 (only the ends of which  
16 are shown), and a second downhole tool 712 to a drill  
17 bit 714.

18  
19 Each of the tools 708 and 712 is similar to the  
20 previously described downhole tools 10, 410, & 610 in  
21 having three skew-axis rollers mounted around its  
22 periphery to provide radial support for the downhole  
23 assembly 700, and to translate rotary motion during use  
24 of the assembly 700 into a longitudinal force acting on  
25 the drill bit 714 to increase its effective weight-on-  
26 bit.

27  
28 The motor housing 704 is coupled to and radially  
29 supported by a roller assembly 716 having a peripheral  
30 array of rollers each having their rotation axis  
31 tangential to a notional circle coaxial with the  
32 longitudinal axis of the assembly 700 (equivalent to  
33 one of the previously described downhole tools but with  
34 a skew angle of 90°, or somewhat like the outer part of  
35 the "antifriction bearing" of US1913365). The effect

1 of the roller assembly 716 is to provide countertorque  
2 for the motor 702, ie, to inhibit anticlockwise  
3 rotation of the motor housing 704 while the motor  
4 output shaft 706 is being driven clockwise by operation  
5 of the motor 702. This countertorque is achieved by  
6 the circumferential alignment of the roller axes in the  
7 roller assembly 716, which prevents free rotation of  
8 the roller assembly 716 (though some limited rotation  
9 may take place due to slippage), though longitudinal  
10 movement of the roller assembly 716, and hence of the  
11 downhole assembly 700, can take place relatively  
12 freely.

13

14 The motor 702 is a hydraulic motor of the Moineau type  
15 which is fed with pressurised hydraulic fluid through a  
16 flexible tube 718 of the type known as "coiled tubing".  
17 The tube 718 is linked to the downhole assembly 700  
18 through a fluid-tight rotary swivel 720 to prevent  
19 rotation of the motor casing 704 (due to slippage of  
20 the roller assembly 716) inducing undesirable  
21 distortions in the tube 718.

22

23 Turning now to Fig. 10, this shows a downhole assembly  
24 800 which is similar in many aspects to the above-  
25 described assembly 700, but which differs in one  
26 substantive respect (detailed below). Those parts of  
27 the assembly 800 which are identical to or equivalent  
28 to like parts of the assembly 700 are given the same  
29 reference numeral, but with the leading "7" substituted  
30 by an "8". Therefore, for a full description of any  
31 part of the assembly 800 not detailed below, reference  
32 should be made to the appropriate part of the foregoing  
33 description of the assembly 700.

34

35 The substantive difference in the downhole assembly 800

1 with respect to the downhole assembly 700 consists in  
2 replacing the roller assembly 716 with a further  
3 downhole tool 830 which is essentially similar to the  
4 downhole tools 808 and 812, except that the hand of the  
5 notional helix is reversed, ie each roller 832 is  
6 mounted on a respective roller axle 834 which is  
7 tangential to a notional helix substantially coaxial  
8 with the longitudinal axis of the tool 830 and  
9 spiralling clockwise ("right hand") in a downward  
10 direction (right to left as viewed in Fig. 10). The  
11 effect of this roller pitch reversal in the tool 830  
12 with respect to the anticlockwise ("left hand") roller  
13 pitch in the tools 808 and 812 is that as the motor  
14 housing 804 contrarotates (anticlockwise as viewed from  
15 above) as a consequence of reacting the clockwise  
16 output torque of the motor output shaft 806, the tool  
17 830 produces a longitudinal force acting in a downward  
18 direction (right to left as viewed in Fig. 10), thus  
19 dynamically adding to the effective "weight" on the  
20 drill bit 814.

21  
22 The tool 830 is preferably set up and adjusted so that  
23 the tool 830 is less susceptible to longitudinal  
24 slippage than the tools 808 and 812. As well as the  
25 adoption of slippage-reducing measures such as  
26 providing the rollers 832 with high-grip surfaces, such  
27 an objective can be attained by additionally or  
28 alternatively urging the rollers 832 radially outwards  
29 of the tool 830, eg by mounting the roller axles 834 on  
30 springs (not shown) arranged to force the axles 834,  
31 and the rollers 832 mounted thereon, radially outwards  
32 of the tool 830; alternatively the axles 834 could be  
33 mounted on pressurisable actuators (not shown), eg  
34 hydraulic piston and cylinder assemblies, disposed to  
35 force the axles 834 and the rollers 832 thereon

1 radially outwards of the tool 830 when suitably  
2 pressurised. Spring enhancement of roller traction  
3 forces (ie radial outward forces) has the advantage of  
4 being continuous and automatic, while hydraulic or  
5 other pressure enhancement of roller traction forces is  
6 capable of being suitably controlled in respect of  
7 factors such as timing and magnitude, thus enabling  
8 better performance of the downhole assembly 800 in  
9 operation thereof.

10

11 Dominance by the tool 830 over the tools 808 and 812 in  
12 terms of their respective contributions to the  
13 production of longitudinal forces in a common downhole  
14 direction can be further assured by making the tools  
15 808 and 812 undergauge, ie by arranging their roller  
16 axle locations and/or the roller diameters to make the  
17 overall outside diameter of the tools 808 and 812  
18 marginally less than the bore of the previously drilled  
19 hole in which the downhole assembly 800 is operated.

20

21 The tools 808 and 812 not only function to provide a  
22 dynamically increased weight-on-bit (as previously  
23 detailed), the tools 808 and 812 additionally function  
24 as stabilisers, ie they function to provide radial  
25 support for the parts of the downhole assembly 800  
26 between and including the motor shaft 806 and the drill  
27 bit 814, allowing relatively low-friction rotation of  
28 these components by reason of the rollers forming the  
29 peripheries of the tools 808 and 812. Thus the dual-  
30 function tools 808 and 812 may conveniently be termed  
31 "traction stabilisers". Similarly, the tool 830 can be  
32 termed the "dominating stabiliser".

33

34 In the Fig. 10 arrangement, the negative effects of the  
35 reaction torque of the motor 802 will be utilized to

1 positive effect, providing an additional thrust or  
2 motive force to that of the traction stabilisers 808  
3 and 812.  
4

5 As the motor output shaft 806 rotates providing torque  
6 to the drill bit 814, the traction stabilizers 808 and  
7 812 provide forward thrust due to their ability to  
8 "walk" into the wellbore under the influence of the  
9 left-hand flutes incorporating the tractive rolling  
10 elements. The pitch of the left-hand helix will be  
11 constructed in such a way that the traction stabilizers  
12 808 and 812 will attempt to "walk" into the wellbore  
13 faster than either the coil-tubing 818 can be unreeled  
14 into the wellbore, or the drill bit 814 can cut into  
15 fresh formation. This situation creates slippage  
16 between the traction stabilizers 808, 812 and the  
17 wellbore.  
18

19 However, although the motor 802 will provide nominally  
20 constant rpm to the drilling assembly, the fact that  
21 the dominating stabilizer 830 is configured to reduce  
22 the opportunity for slippage will cause a change in the  
23 relative rotational speeds of the motor rotor 806 and  
24 motor casing 804 with respect to the wellbore. It is  
25 envisaged that the motor casing 804 will slow down in  
26 direct proportion to the reduction in forward motion  
27 from the calculated on the basis of the helix angle.  
28 The reduced rotational speed of the motor casing 804  
29 will be compensated by an increase in the rotational  
30 speed of the rotor 806, thereby providing the same  
31 thrust to the drillbit 814, irrespective of the  
32 rotational fluctuations of the assembly 800. In short,  
33 this system will provide automatic compensation of the  
34 weight-on-bit longitudinal thrust provided at the  
35 drillbit 814.

1 To illustrate more fully and clearly the mechanism of  
2 operation the following numerical illustration is shown  
3 by way of example, although the figures given are not  
4 mandatory in every case.

5  
6 Given that the best operation of typical coil-tubing is  
7 RIH ("run into hole") @ 1000 ft/hr it is imperative  
8 that the motive force provided by the traction  
9 stabilizers is configured for significantly more  
10 longitudinal progress than this.

11  
12  $1000 \text{ ft/hr} = 0.28 \text{ ft/sec}$

13  $5 \text{ miles/hr} = 7.33 \text{ ft/sec}$

14  
15 In effect this means that the traction stabilizers  
16 would "walk" downhole at 7.33 ft/sec but are  
17 constrained to 0.28 ft/sec, roughly 4% of their  
18 capability. The remaining capability must therefore be  
19 dissipated as slippage between the traction stabilizers  
20 and the wall of the wellbore.

21  
22 If the motor 802 is designed to operate at 400 rpm, and  
23 uses 300 rpm to drive the rotor 806 (and therefore the  
24 traction stabilizers 808 and 812) the remaining 100 rpm  
25 would be seen at the motor casing/dominating stabilizer  
26 interface.

27  
28 Given that the dominating stabilizer 830 will not slip,  
29 the rotational speed of the motor casing 804 will  
30 reduce from 100 rpm to 4 rpm, to compensate for the  
31 reduction in forward motion of the stabilizers 808 and  
32 812, in direct proportion. Equally, the remaining  
33 96 rpm will now transfer to the motor's rotor 806, and  
34 its shaft speed can be transferred back and forth  
35 between the rotor 806 and the casing 804 to provide a

1 constant thrust to the drill bit 814.

2  
3 It is possible that due to the very shallow angles  
4 involved in the setting of the left-hand stabilizers  
5 808 and 812 that a mechanism can be developed which  
6 inverts the orientation of the flutes and hence the  
7 helix angle of the rollers such that for a continued  
8 input rotation the downhole assembly would now "walk"  
9 back out of the hole.

10  
11 Referring now to Fig. 11, this schematically  
12 illustrates a downhole assembly 900 which is a  
13 modification of the assembly 800 described above with  
14 reference to Fig. 10. The assembly 900 is configured  
15 to function as a pipe crawler or pipe tug assembly  
16 capable of pulling pipes, cables, inspection and  
17 testing equipment, and the like along tunnels,  
18 conduits, and similar underground passages that have  
19 been formed prior to the passage of the assembly 900.  
20 Those parts of the assembly 900 which correspond to  
21 equivalent or analogous parts of the assembly 800 are  
22 given the same reference numeral, but with the leading  
23 "8" replaced by a "9"; reference should be made to the  
24 appropriate parts of the preceding description for  
25 details of any part of the assembly 900 not described  
26 below.

27  
28 In the assembly 900, items forward (downhole or  
29 leftwards as viewed in Fig. 11) of the tool/stabilizer  
30 908 are removed and replaced by a bull-nose 940. The  
31 rear or uphole end of the assembly 900 is fitted with a  
32 cable attachment 950 to which (for example) a cable 960  
33 may be attached to be dragged through the bore 970 by  
34 means of the assembly 900.

35

1 The motor 902 would drive the traction stabiliser 908  
2 which would "walk" along the pipe or conduit 970. The  
3 dominating stabilizer 930 would be configured to drag  
4 the cable 960 behind it as the assembly 900 rotated and  
5 moved along the pipe 970. To obviate the difficulties  
6 encountered at a bend in the pipe 970 it is envisaged  
7 that the pipe tug assembly 900 would have a universal  
8 coupling 980 (eg a Hooke joint) between the motor 902  
9 and the traction stabiliser 908, thereby enabling the  
10 assembly 900 to negotiate bends until limited by radii  
11 smaller than the longest section length of the pipe tug  
12 assembly 900.

13

14 It is also preferred that the aforementioned mechanism  
15 to reverse the helix angle of the tractive elements 908  
16 and 930 is included in the assembly 900. This would  
17 enable the traction stabilizer to "walk" out of the  
18 pipe for the same given rotation.

19

20 Figs 12 - 14 show a downhole drilling assembly 1000  
21 essentially similar to the downhole assembly 80 of Fig.  
22 10, but in more detail and somewhat less schematically.  
23 Parts of the assembly 1000 which directly correspond to  
24 parts of the assembly 800 are given the same reference  
25 numerals, but with the leading "8" replaced by "10"  
26 (eg, in Fig. 14, the motor which is equivalent to the  
27 motor 802 of Fig. 10 is denoted "1002"). For a  
28 detailed description of the parts of the assembly 1000  
29 and their operation, reference should be made to the  
30 foregoing description of the equivalent parts of the  
31 assembly 800 and their operation.

32

33 Fig. 12 is an elevational view of either one of the  
34 mutually identical downhole tools or traction  
35 stabilizers 1008 and 1012, while Fig. 13 is a plan view

1 from above of the traction stabilisers 1008, 1012 (ie a  
2 view from the left in Fig. 14 wherein the assembly 1000  
3 is oppositely oriented to the assembly 800 as depicted  
4 in Fig. 10). Fig. 14 is an elevation of the assembly  
5 1000 drilling through geological material 1099 (in a  
6 direction from left to right as viewed in Fig. 14).  
7 Operation of the assembly 1000 and of its constituent  
8 parts is as previously described in respect of the  
9 assembly 800 (Fig. 10).

10

11 Figs 15 and 16 illustrate a downhole tool which is a  
12 variation on the previously described downhole tools.  
13 Fig. 15 is a longitudinal elevation of the outline of  
14 the tool 1100 in an operational position within the  
15 tubular casing 1190, while Fig. 16 is a longitudinal  
16 section of the tool 1100 taken on a plane which is  
17 vertical to the centre line of Fig. 15, and viewed in a  
18 direction which is right to left in Fig. 15.

19

20 In the previously described downhole tools, the rollers  
21 or other rolling elements had individual diameters  
22 which were small relative to the overall peripheral  
23 diameter of the tool. However, the tool 1100 differs  
24 in that the rolling elements (detailed below) have  
25 individual diameters which are more nearly equal to  
26 (though still less than) the overall peripheral  
27 diameter of the tool.

28

29 Referring specifically to Fig. 16, the tool 1100  
30 comprises a tubular central member 1102 upon which are  
31 mounted two spaced-apart single-row ball bearings 1104  
32 and 1106 each fitted with respective toughened tyre  
33 1108, 1110 formed of metal, polymer, or any other  
34 suitable material.

35

1 Each of the bearings 1104 and 1106 is mounted on a  
2 respective tilt bearing 1112 and 1114 whose mutually  
3 parallel rotational axes are each diametrically aligned  
4 with respect to the longitudinal axis of the central  
5 member 1102. The bearing 1104 and 1106 are coupled by  
6 means (not shown) for controllable conjoint tilting in  
7 parallel planes about their respective tilt bearings  
8 1112, 1114 such that each of the bearings 1104, 1106  
9 rotates about a respective axis which is angularly  
10 skewed with respect to the longitudinal axis of the  
11 central member 1102. These rotation axes of the  
12 bearings 1104 and 1106 are also laterally offset from  
13 the longitudinal axis, in a direction which is upwards  
14 from the plane of Fig. 16, and rightwards in Fig. 15.

15  
16 Between the mutually longitudinally spaced-apart  
17 bearings 1104 and 1106, the central member 1102 mounts  
18 a cluster of three mutually coaxial bearings 1116,  
19 1118, and 1120 each dimensionally identical to the  
20 bearings 1104 & 1106, and each likewise being fitted  
21 with a respective toughened tyre. Each of the ball  
22 bearing 1116, 1118 and 1120 rotates about the same  
23 rotation axis which is parallel to the longitudinal  
24 axis of the central member 1102 (ie rotation axis is  
25 non-skewed), and laterally offset equally and  
26 oppositely to the lateral offset of the rotation axes  
27 of the bearings 1104 and 1106, ie the common rotation  
28 axis of the bearings 1116, 1118, and 1120 is displaced  
29 in a direction which is downwards from the plane of  
30 Fig. 16, and leftwards in Fig. 15.

31  
32 Thus the bearing pair 1104, 1106, and the bearing  
33 triplet 1116-1120 contact mutually opposite sides of  
34 the casing 1190, as most clearly shown in Fig. 15, thus  
35 to provide mutually opposed radial forces causing these

1     varying the skew angles of the rollers. The rollers  
2     1204, 1206 and 1208 preferably incorporate peripheral  
3     inserts 1210 of a hard wear-resistant material (eg  
4     tungsten carbide), the rollers thereby superficially  
5     resembling 'slices' of a conventional hard-faced  
6     fixed-blade stabiliser.

7  
8     Figs 18 and 19 are respectively a schematic elevation  
9     and an end view illustrating a developed form of a  
10    "large roller" downhole tool based on the above  
11    described principles. In the downhole tool 1300 as  
12    schematically depicted in Fig. 18, a longitudinally  
13    extending central member 1302 mounts six large diameter  
14    rollers 1304, 1306, 1308, 1310, 1312, and 1314 at  
15    spaced-apart locations along the central member 1302.  
16    Each of the rollers 1304-1314 has a respective rotation  
17    axis which is both laterally offset and angularly  
18    skewed with respect to the longitudinal axis of the  
19    central member 1302, ie the centre line of the tool  
20    1300, as depicted in Fig. 19. As shown in Fig. 18, the  
21    rollers 1304-1314 have equal increments of mutual  
22    angular displacement of their respective lateral  
23    offsets, but this is not actually essential, the  
24    requirement being that the lateral offsets be angularly  
25    distributed in the tool as a whole such as to provide a  
26    net balance of radial forces, ie such that a force in  
27    any one radial direction is balanced by a diametrically  
28    opposed radial force (or resultant of two or more  
29    radial forces).

30  
31    Each of the rollers 1304-1314 contacts the surrounding  
32    casing 1390 at a respective point of contact (labelled  
33    "1" - "6" in Fig. 18) at which the circumference of the  
34    respective roller makes a small angle (equal to the  
35    skew angle) with respect to a purely circumferential

1 bearing groups each to bear against the inner face of  
2 the casing 1190. The skew angle of the bearing pair  
3 1104 and 1106 results in a longitudinal force being  
4 developed as the tool 1100 rotates within the casing  
5 1190, this longitudinal force being directed upwards as  
6 viewed in Figs 15 and 16 when the direction of rotation  
7 is clockwise as viewed from above and looking  
8 downwards.

9  
10 Fig. 17 is a perspective view of a downhole tool 1200  
11 based on the "large roller" principle described above  
12 with reference to Figs 15 and 16. In the tool 1200, a  
13 central tubular member 1202 rotatably mounts upper and  
14 lower rollers 1204 and 1206 on respective rotation axes  
15 which are angularly skewed with respect to and  
16 laterally offset from the longitudinal axis of the tool  
17 1200, as described above in respect of the rollers 1104  
18 and 1106 in the downhole tool 1100 of Figs 15 and 16.  
19 The central member 1202 also rotatably mounts a central  
20 roller 1208 on a respective rotation axis which is  
21 laterally offset from the longitudinal axis of the tool  
22 1200 by an amount equal to and in a direction opposite  
23 to the lateral offset of the rotation axes of the upper  
24 and lower rollers 1204 and 1206. The rotation axis of  
25 the central roller 1208 may be parallel to the  
26 longitudinal axis, or it may be skewed to match the  
27 skew of the rotation axes of the upper and lower  
28 rollers 1204 and 1206. Means (not shown) may be  
29 incorporated into the tool 1200 to cause the rollers  
30 1204, 1206, and 1208 to be mechanically and/or  
31 hydraulically urged radially outwards in a controlled  
32 or uncontrolled manner against the bore of the casing  
33 or other tubular cavity within which the tool 1200 is  
34 being operated. Further means (not shown) may be  
35 incorporated into the tool 1200 for controllably

1 direction around the bore of the casing 1390 at that  
2 point, such that if the tool 1300 rolled around inside  
3 the casing 1390 without slipping, these points of  
4 contact would trace out paths equivalent to a screw-  
5 thread around and along the base of the casing. Thus  
6 at the same time as the tool 1300 provides rotational  
7 support for a downhole assembly of which it forms part,  
8 rotation of the tool 1300 tends to develop a  
9 longitudinal force driving the tool along the casing.

10  
11 Fig. 20 (elevation) and Fig. 21 (plan) schematically  
12 depict a downhole tool 1400 which is a modification of  
13 the tool 1300 described above with reference to Figs 18  
14 and 19. In Figs 20 and 21, these parts of the modified  
15 tool 1400, which are equivalent or analogous to parts  
16 of the tool 1300 are given the same reference numerals,  
17 but with the leading "13" replaced by a "14"; for a  
18 description of any part of the tool 1400 not detailed  
19 below, reference should be made to the relevant part of  
20 the preceding description of the tool 1300.

21  
22 In the tool 1400, the central roller-mounting 1402 has  
23 the general form of a helix, each of the rollers  
24 1404-1414 being centrally mounted on the helical member  
25 1402 such that the required combination of lateral  
26 offset and skew angle for each of the rollers 1404-1414  
27 is provided by the helical displacement of the member  
28 1402 from the longitudinal axis of the tool 1400,  
29 rather than by offsetting the individual mounting of  
30 each roller as in the Fig. 19 arrangement. The tool  
31 1400 functions in the same manner as does the tool  
32 1300.

33  
34 While certain modifications and variations of the  
35 invention have been described above, the invention is

1 not restricted thereto, and other modifications and  
2 variations can be adopted without departing from the  
3 scope of the invention as defined in the appended  
4 Claims.  
5

1     CLAIMS

2

3     1.   A downhole tool for providing radial support for a  
4       rotatable downhole assembly within a previously drilled  
5       hole of substantially uniform diameter, said tool  
6       comprising a central member constructed or adapted to  
7       be incorporated in a rotatable downhole assembly for  
8       rotation therewith in use of said tool, said central  
9       member mounting a plurality of rolling element means in  
10      respective positions which are circumferentially  
11      distributed around said tool, each said rolling element  
12      means being rotatably mounted on a respective axis  
13      which is tangential to a notional helix substantially  
14      coaxial with the longitudinal axis of said tool about  
15      which said tool rotates in use of said tool such that  
16      each said respective axis of said rolling element means  
17      is skewed with respect to said longitudinal axis, each  
18      said rolling element means having a respective  
19      periphery which extends to the radially outermost  
20      periphery of said tool whereby the radially outermost  
21      periphery of said tool provides rolling radial support  
22      for said rotatable downhole assembly in use of said  
23      tool by means of the peripheries of said rolling  
24      element means and the rotation of said rolling element  
25      means about their skewed axes translates rotation of  
26      said tool in use thereof to a longitudinally-directed  
27      force acting through said central member on said  
28      downhole assembly.

29

30     2.   A downhole tool as claimed in Claim 1 wherein said  
31       rotatable downhole assembly is a drillstring and said  
32       notional helix is contra-rotary with respect to the  
33       combination of the normal or forward direction of  
34       rotation of the drillstring and the direction from said  
35       tool towards a drill bit at the downhole end of the

1 drillstring, whereby normal or forward rotation of said  
2 drillstring and of the tool incorporated therein  
3 results in a longitudinal force tending to propel the  
4 drillstring towards the blind end of the bore and  
5 ultimately tending to force the drill bit into the  
6 geological material to be drilled.

7  
8 3. A downhole tool as claimed in Claim 2 wherein said  
9 normal or forward direction of rotation of the  
10 drillstring is clockwise as viewed from the surface and  
11 looking down into the bore and said notional helix  
12 progresses anti-clockwise in a downhole direction  
13 therealong whereby the peripheries of said rolling  
14 element means, where they extend to the radially  
15 outermost periphery of the tool, align with a notional  
16 right-hand thread around the outer periphery of said  
17 tool.

18  
19 4. A downhole tool as claimed in any preceding Claim,  
20 wherein each respective axis of said rolling element  
21 means is skewed with respect to the longitudinal axis  
22 of the tool at an angle in the range from a very low  
23 (but non-zero) angle, up to 45°, and more preferably at  
24 an angle in the range from 0.5 to 15°.

25  
26 5. A downhole tool as claimed in any preceding Claim,  
27 wherein said downhole tool incorporates skew angle  
28 variation means operable to make the skew angle  
29 controllably variable.

30  
31 6. A downhole tool as claimed in Claim 5, wherein  
32 said skew angle variation means is capable of reversing  
33 the hand of said notional helix whereby the direction  
34 of the longitudinal force is reversed without reversing  
35 the direction of rotation.

1 7. A downhole tool as claimed in any preceding Claim,  
2 wherein said rolling element means are rollers, and the  
3 peripheries of said rollers are individually  
4 cylindrical or crowned.

5

6 8. A downhole tool as claimed in any preceding Claim,  
7 wherein said rollers are individually mounted on a  
8 respective axis.

9

10 9. A downhole tool as claimed in Claim 7, wherein  
11 said rollers are mounted in coaxial groups, such that  
12 within a group of rollers, individual rollers of that  
13 group are capable of rotating at mutually differing  
14 rotational rates.

15

16 10. A downhole tool as claimed in any preceding Claim,  
17 wherein radial force applying means are incorporated in  
18 the tool for applying radially outwardly directed  
19 radial forces to the rolling element means to increase  
20 their traction on the bore.

21

22 11. A downhole tool as claimed in Claim 10 wherein the  
23 radial force applying means is such that the radially  
24 outwardly directed radial forces applied to the rolling  
25 element means are controllably variable.

26

27 12. A rotatable downhole assembly for rotatable  
28 operation within a previously drilled hole of  
29 substantially uniform diameter, said downhole assembly  
30 comprising a downhole motor having a motor housing and  
31 a rotatable motor output shaft coupled to a rotatable  
32 motor output utilisation means, said downhole assembly  
33 further comprising at least one downhole tool as  
34 claimed in any preceding Claim, said at least one  
35 downhole tool being coupled between said rotatable

1 motor output shaft and said rotatable motor output  
2 utilisation means for rotation therewith in operation  
3 of said assembly to provide radial support therefor and  
4 to translate such rotation to a longitudinally-directed  
5 force acting through said motor output utilisation  
6 means.

7  
8 13. A downhole assembly as claimed in Claim 12,  
9 wherein said downhole assembly comprises a plurality of  
10 such downhole tools, each as claimed in any of Claims  
11 1-11, and each being coupled between said rotatable  
12 motor output shaft and said rotatable motor output  
13 utilisation means.

14  
15 14. A downhole assembly as claimed in Claim 12 or  
16 Claim 13, wherein said rotatable motor output  
17 utilisation means comprises a drill bit, said at least  
18 one downhole tool comprised in said downhole assembly  
19 being formed dynamically to increase the effective  
20 weight-on-bit during normally directed rotation of said  
21 drill bit by said downhole motor.

22  
23 15. A downhole assembly as claimed in any of Claims  
24 12-14, wherein said motor housing is coupled to  
25 countertorque means for reacting motor torque output by  
26 said motor output shaft, said countertorque means  
27 rotationally constraining said motor housing with  
28 respect to said previously drilled hole.

29  
30 16. A downhole assembly as claimed in Claim 15,  
31 wherein said countertorque means provides a rotational  
32 braking effect while allowing relative freedom of  
33 movement in a longitudinal direction.

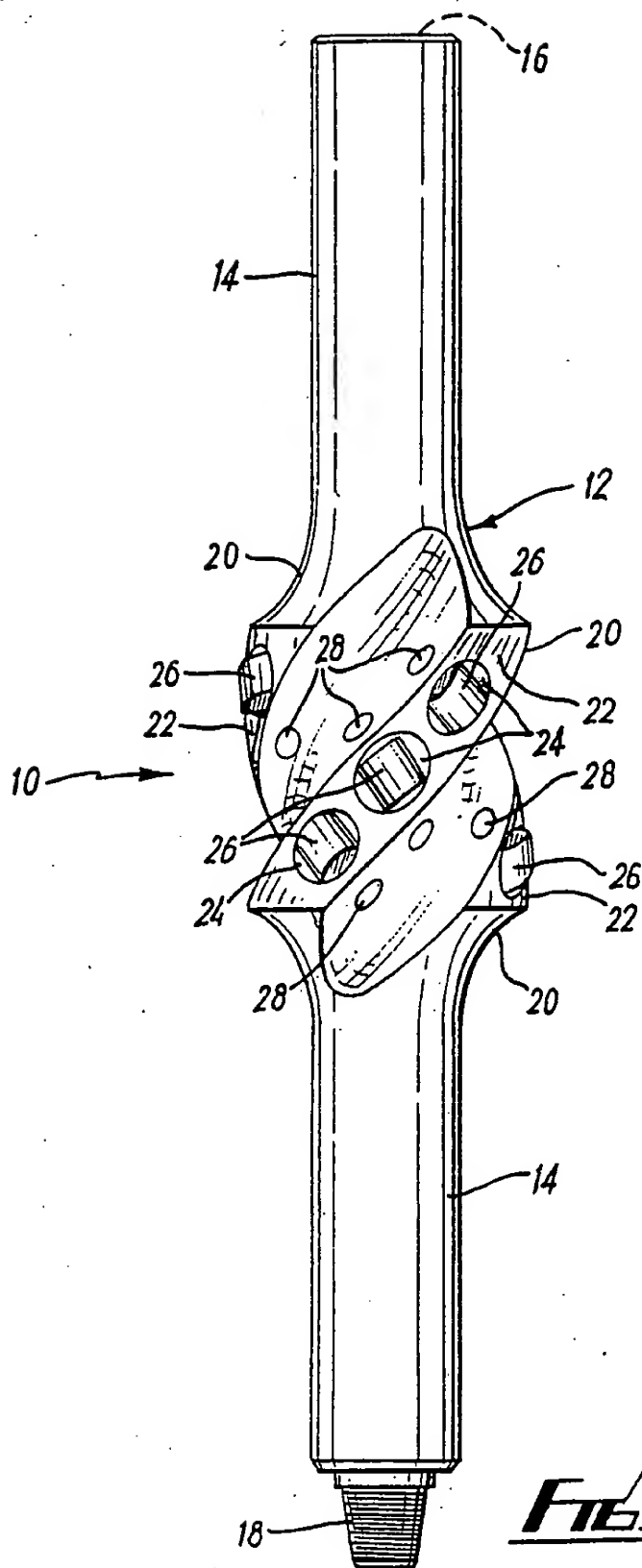
34  
35 17. A downhole assembly as claimed in Claim 16,

1 wherein said rotational braking effect is provided by  
2 forming said countertorque means with a peripheral  
3 array of hole-contacting rotatable rollers having their  
4 axes of rotation substantially tangential to notional  
5 circles substantially coaxial with the longitudinal  
6 axis of said downhole assembly.

7  
8 18. A downhole assembly as claimed in Claim 16,  
9 wherein said countertorque means comprises a further  
10 downhole tool as claimed in any of Claims 1-11, the  
11 notional helix of said further downhole tool being  
12 oppositely handed with respect to the notional helix of  
13 said at least one downhole tool coupled between said  
14 rotatable motor output shaft and said rotatable motor  
15 output utilisation means whereby relative  
16 contrarotation of said motor housing with respect to  
17 said motor output shaft results in commonly directed  
18 longitudinal forces at said at least one and further  
19 downhole tools comprised in said downhole assembly.

20  
21 19. A downhole assembly as claimed in any of Claims  
22 12-18, wherein the motor of said downhole assembly is a  
23 hydraulic motor supplied in operation thereof with  
24 pressurised fluid by way of tubing which may be  
25 flexible, said downhole assembly being coupled to said  
26 tubing by way of a swivel coupling which is  
27 substantially fluid-tight.

28  
29 20. A downhole assembly as claimed in any of Claims  
30 12-19, wherein said downhole assembly has major  
31 components and sub-assemblies thereof longitudinally  
32 coupled by one or more couplings transmissive of torque  
33 and longitudinal forces but yieldable about axes  
34 transverse to the longitudinal axis whereby the  
35 downhole assembly may conform to bent holes.

**Fig. 1**

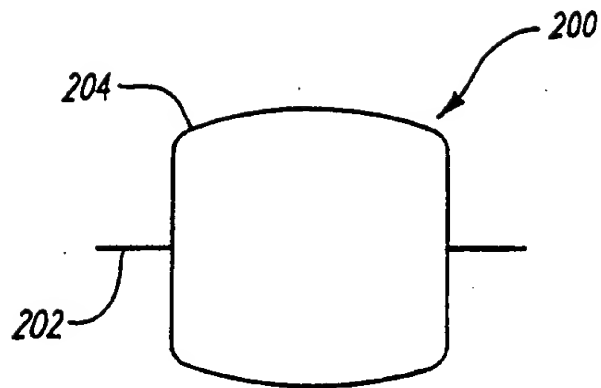


FIG. 2

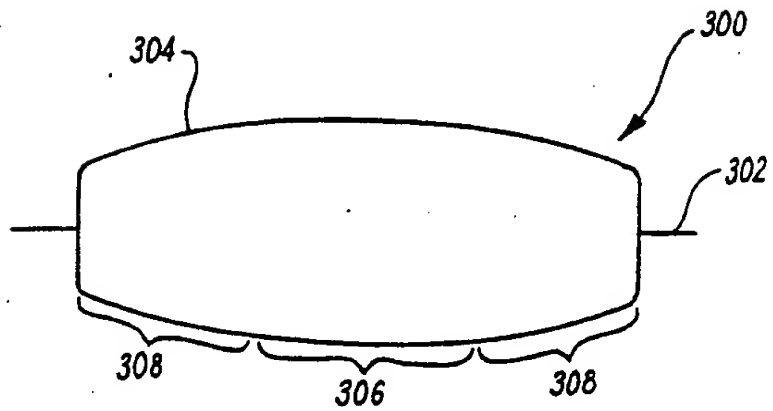
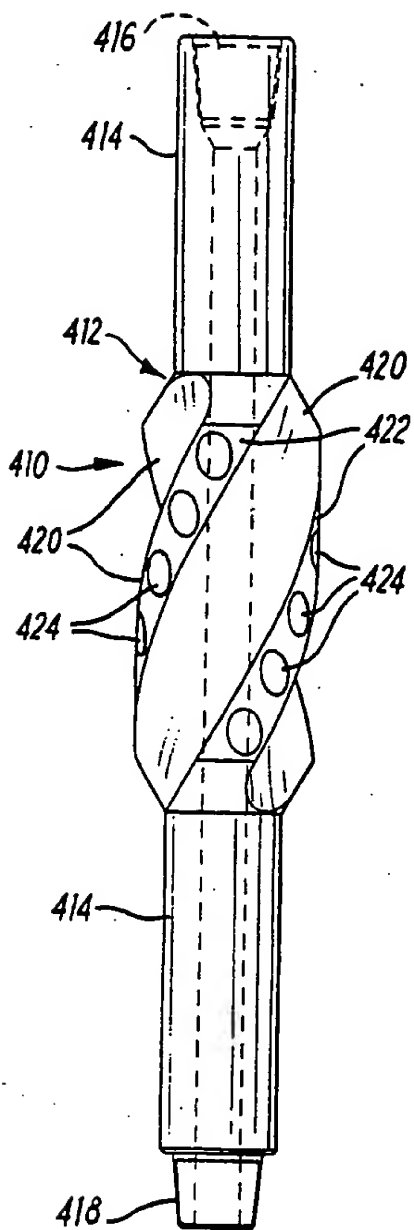
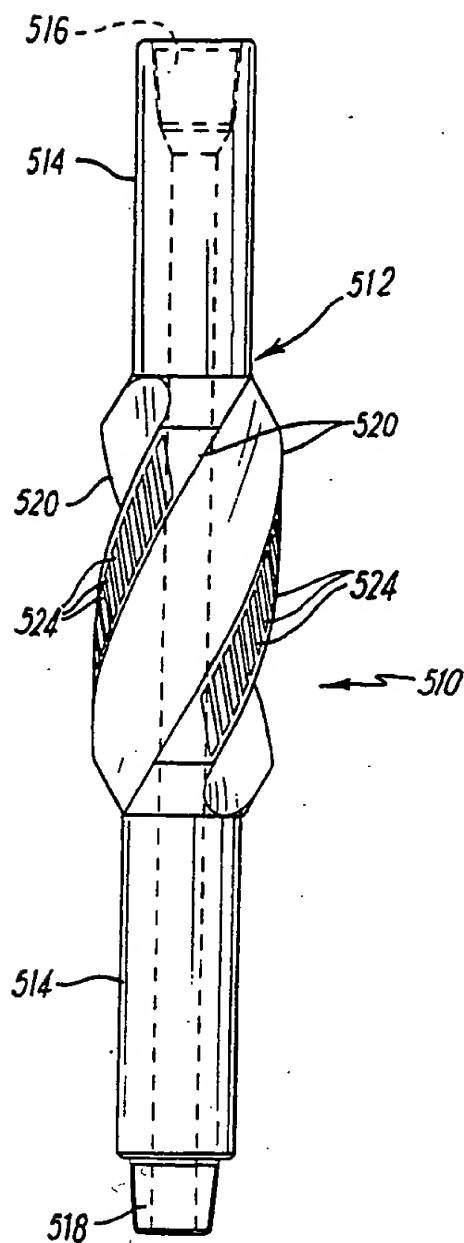
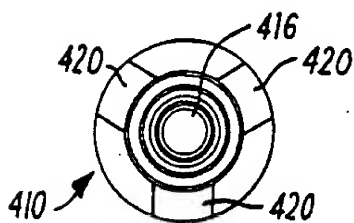
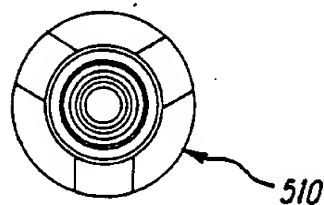
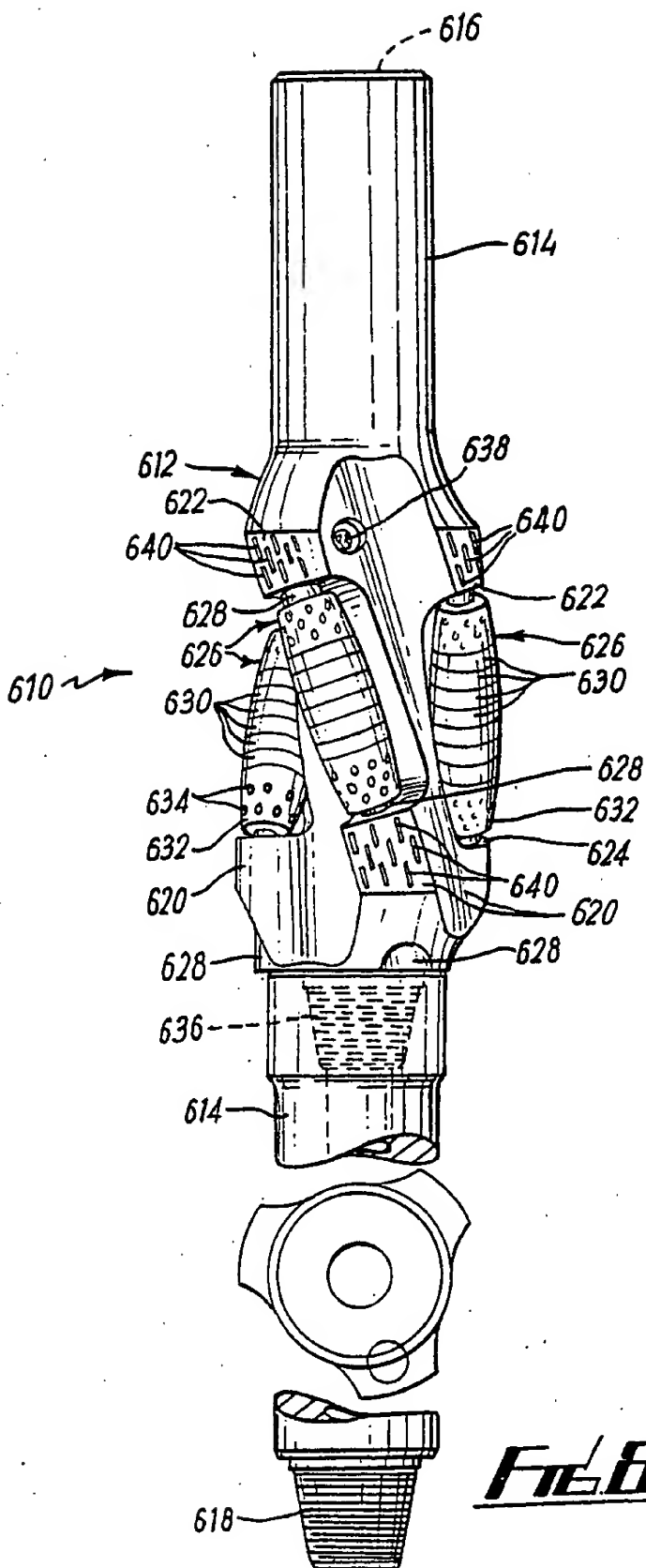
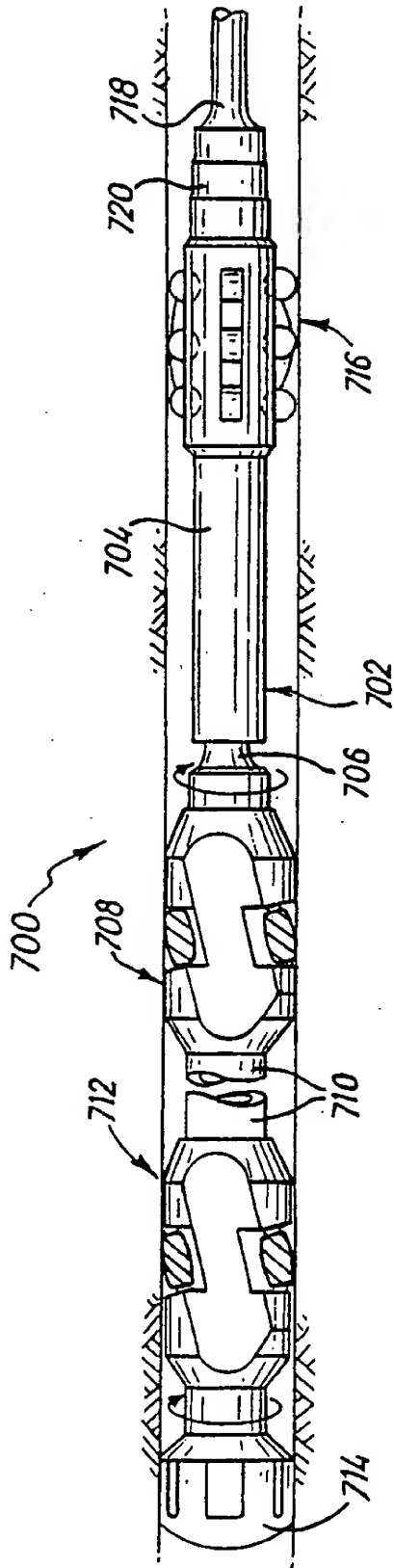


FIG. 3

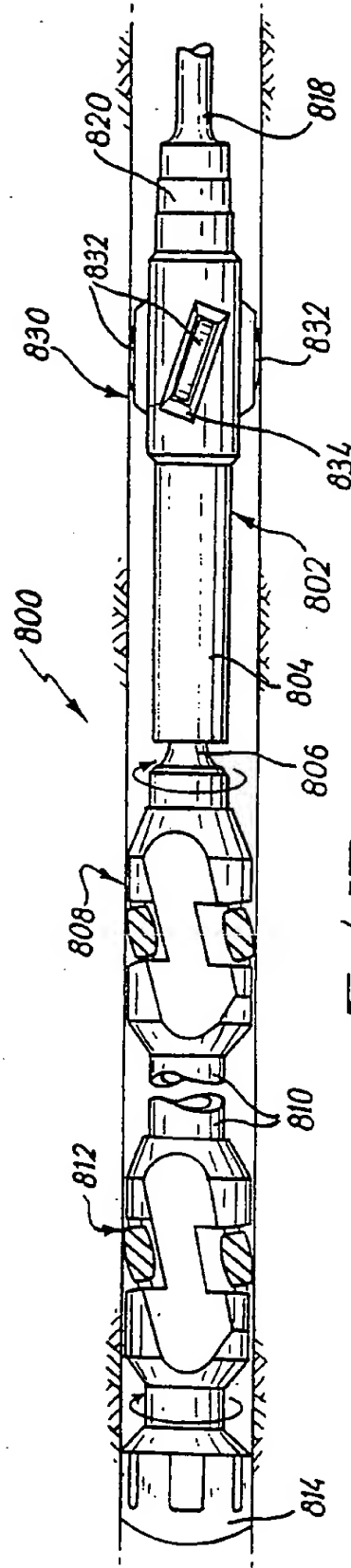
**FIG. 4****FIG. 6****FIG. 5****FIG. 7**



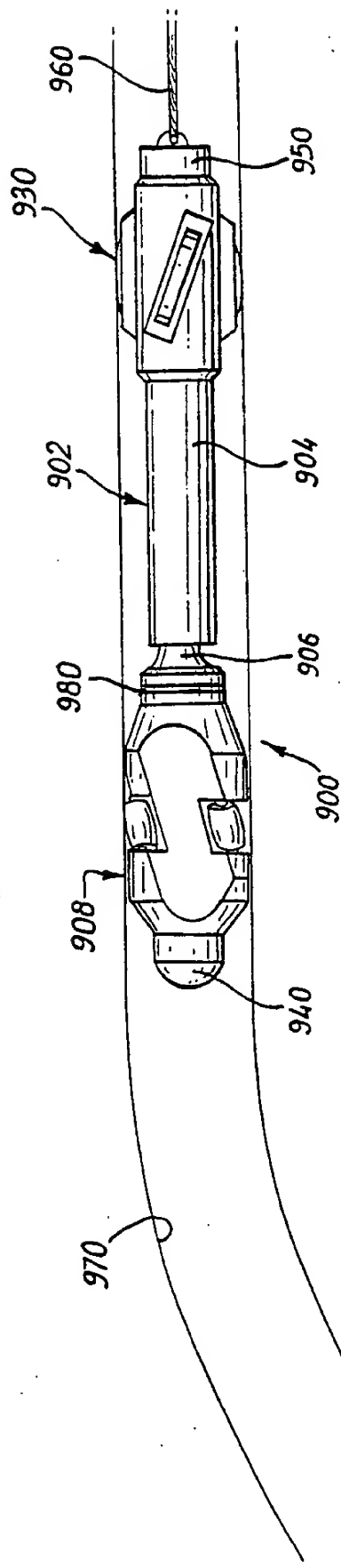
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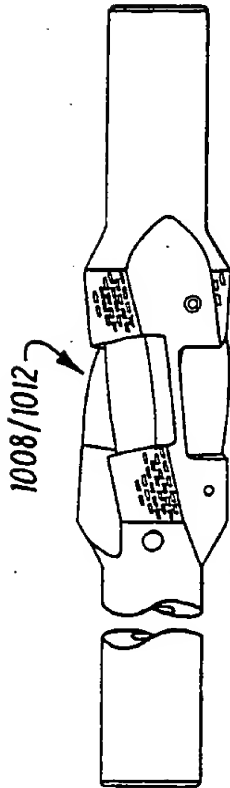
**Fig. 9**



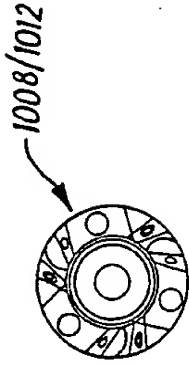
**Fig. 10**



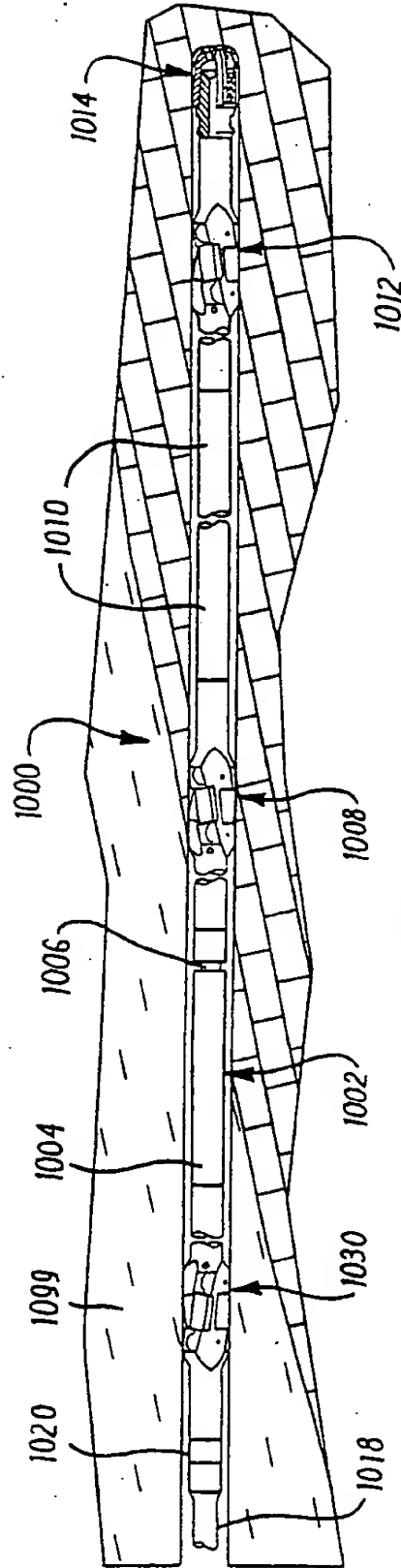
**Fig. 11**



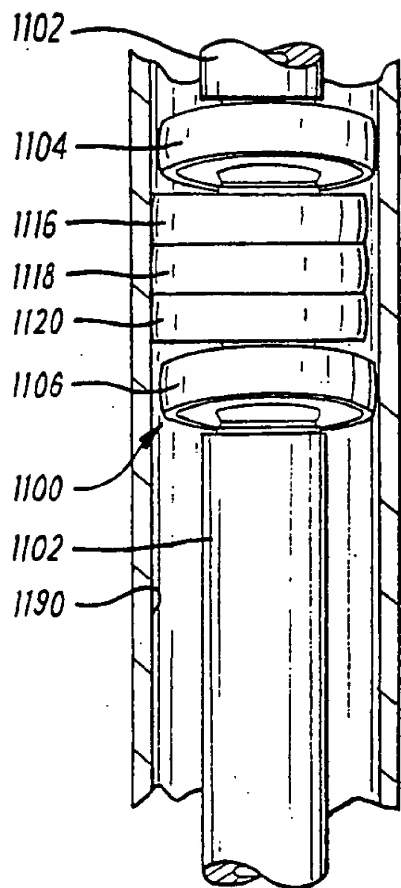
**Fig 12**



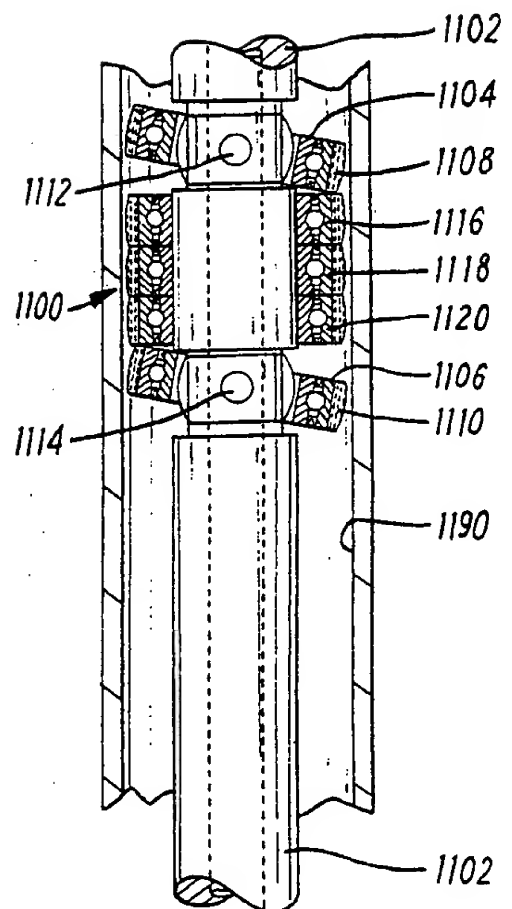
**Fig 13**



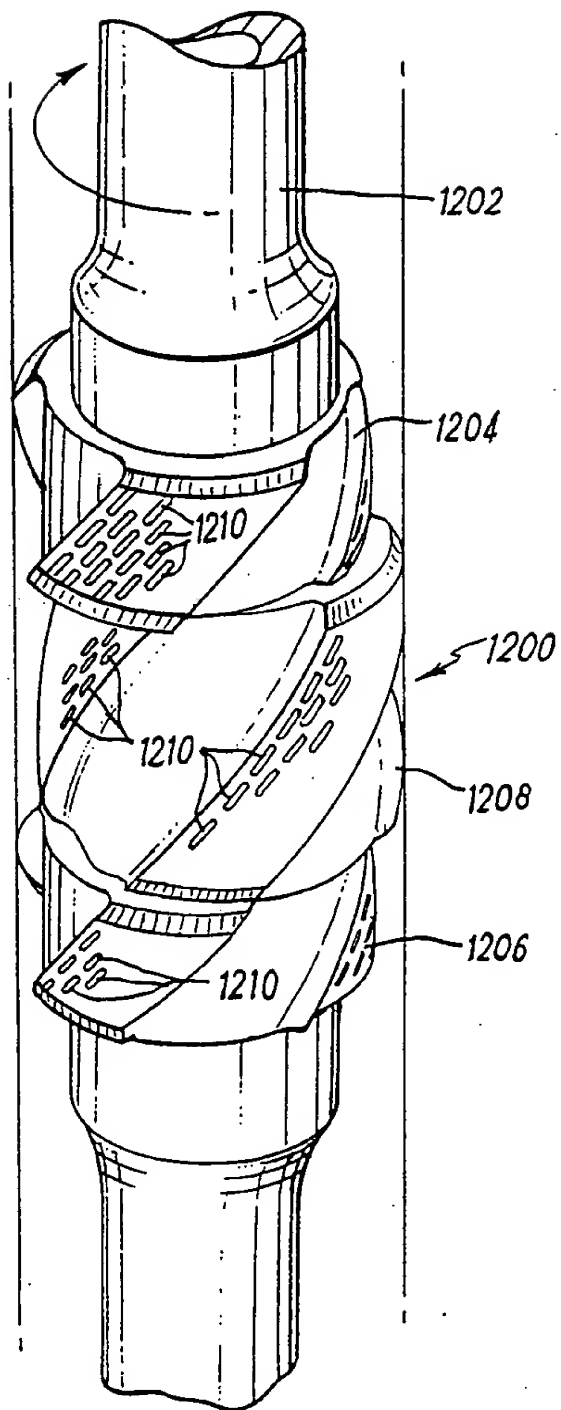
**Fig 14**

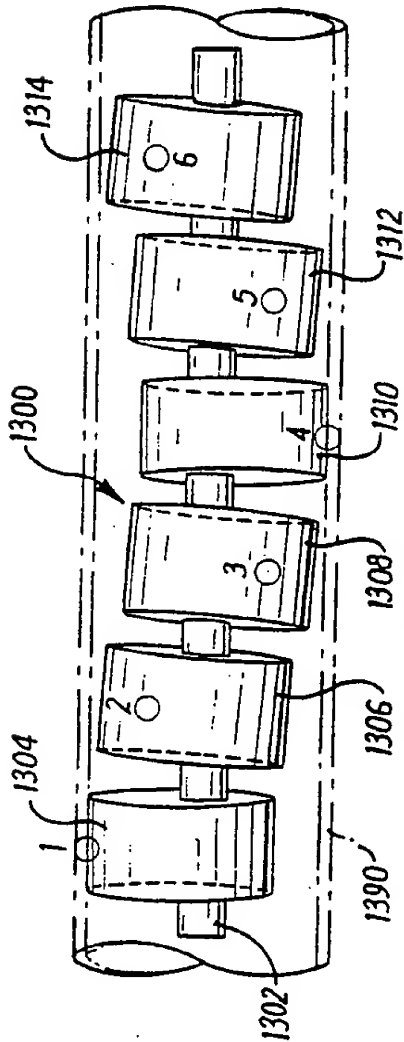


**FIG. 15**

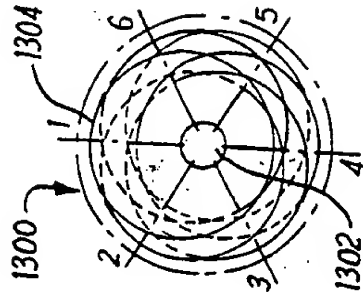


**FIG. 16**

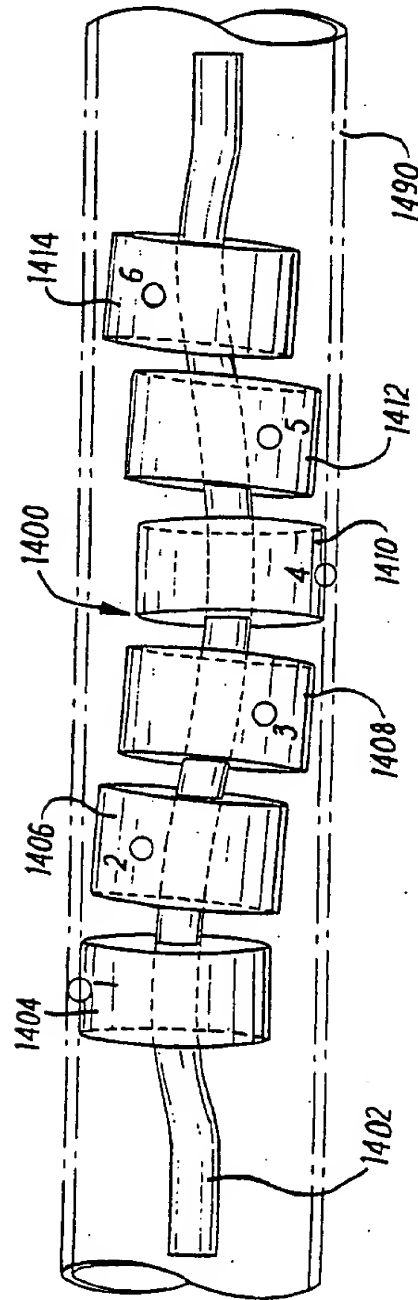
**FIG. 17**



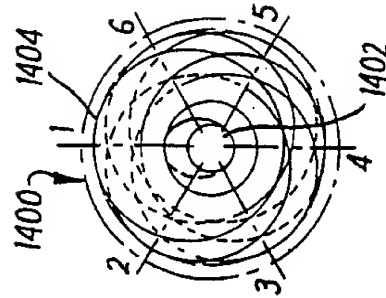
**Fig. 18**



**Fig. 19**



**Fig. 20**



**Fig. 21**

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/GB 93/01114

## A. CLASSIFICATION OF SUBJECT MATTER

IPC5: E21B 17/10

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC5: E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 4365678 (J.L. FITCH), 28 December 1982 (28.12.82), column 1; column 3, line 11 - line 27	1,7,12-14, 19-20
	--	
A	EP, A1, 0333450 (ANDERSON, C.A.), 20 Sept 1989 (20.09.89)	1-20
	-- -----	

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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- \* "O" document referring to an oral disclosure, use, exhibition or other means
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Date of the actual completion of the international search

13 Sept 1993

Date of mailing of the international search report

29.09.93

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**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

26/08/93

International application No.

PCT/GB 93/01114

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4365678	28/12/82	US-A- 4465146	14/08/84
EP-A1- 0333450	20/09/89	US-A- 4958692	25/09/90

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